SEMIARID PRECIPITATION FREQUENCY PROJECT

Update of *Technical Paper No. 49* and *NOAA Atlas 2*

Twenty-fifth Progress Report
1 April 2003 through 30 June 2003

Hydrometeorological Design Studies Center
Hydrology Laboratory

Office of Hydrologic Development
U.S. National Weather Service
National Oceanic and Atmospheric Administration
Silver Spring, Maryland

July 2003

DISCLAIMER

The data and information presented in this report should be considered as preliminary and are provided only to demonstrate current progress on the various technical tasks associated with this project. Values presented herein are NOT intended for any other use beyond the scope of this progress report. Anyone using any data or information presented in this report for any purpose other than for what it was intended does so at their own risk

TABLE OF CONTENTS

1. Introduction 1

2. Highlights 4

3. Progress in this Reporting Period 5

4. Issues 9

5. Projected Schedule and Remaining Tasks 9

References 11

Appendix A 12

SEMIARID PRECIPITATION FREQUENCY PROJECT

Update of *Technical Paper No. 49* and *NOAA Atlas 2*

1. Introduction

The Hydrometeorological Design Studies Center (HDSC), Hydrology Laboratory, Office of Hydrologic Development, U.S. National Weather Service is updating its precipitation frequency estimates for the Semiarid Southwestern United States. Current precipitation frequency estimates for the Semiarid region are contained in *Technical Paper No. 49* "Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States" (Miller et al 1964), *NOAA Atlas 2* "Precipitation-Frequency Atlas of the Western United States" (Miller et al 1973), "Short Duration Rainfall Frequency Relations for California" (Frederick and Miller, 1979) and "Short Duration Rainfall Relations for the Western United States" (Arkell and Richards, 1986). The new project includes collecting data and performing quality control, compiling and formatting datasets for analyses, selecting applicable frequency distributions and fitting techniques, analyzing data, mapping and preparing reports and other documentation.

The project will determine annual all-season precipitation frequencies for durations from 5 minutes to 60 days, for return periods from 2 to 1000 years. The project will review and process all available rainfall data for the Semiarid project area and use accepted statistical methods. In particular, the Semiarid Project is the pilot project in which decisions regarding the methods and format are being made that will affect subsequent projects. The project results will be published as Volumes of *NOAA Atlas 14* on the internet using web pages with the additional ability to download digital files.

The Semiarid Project will produce estimates for 4 states completely, Arizona, Nevada, New Mexico, and Utah, and southeastern California. Additional data from 7 bordering states and Mexico (Figure 1) are included for continuity across state borders. The core and border areas and regional groups for long duration (24-hour through 60-day) analyses are shown in Figure 1. Regional groups for short duration (60-minute through 12-hour) analyses are shown in Figure 2.

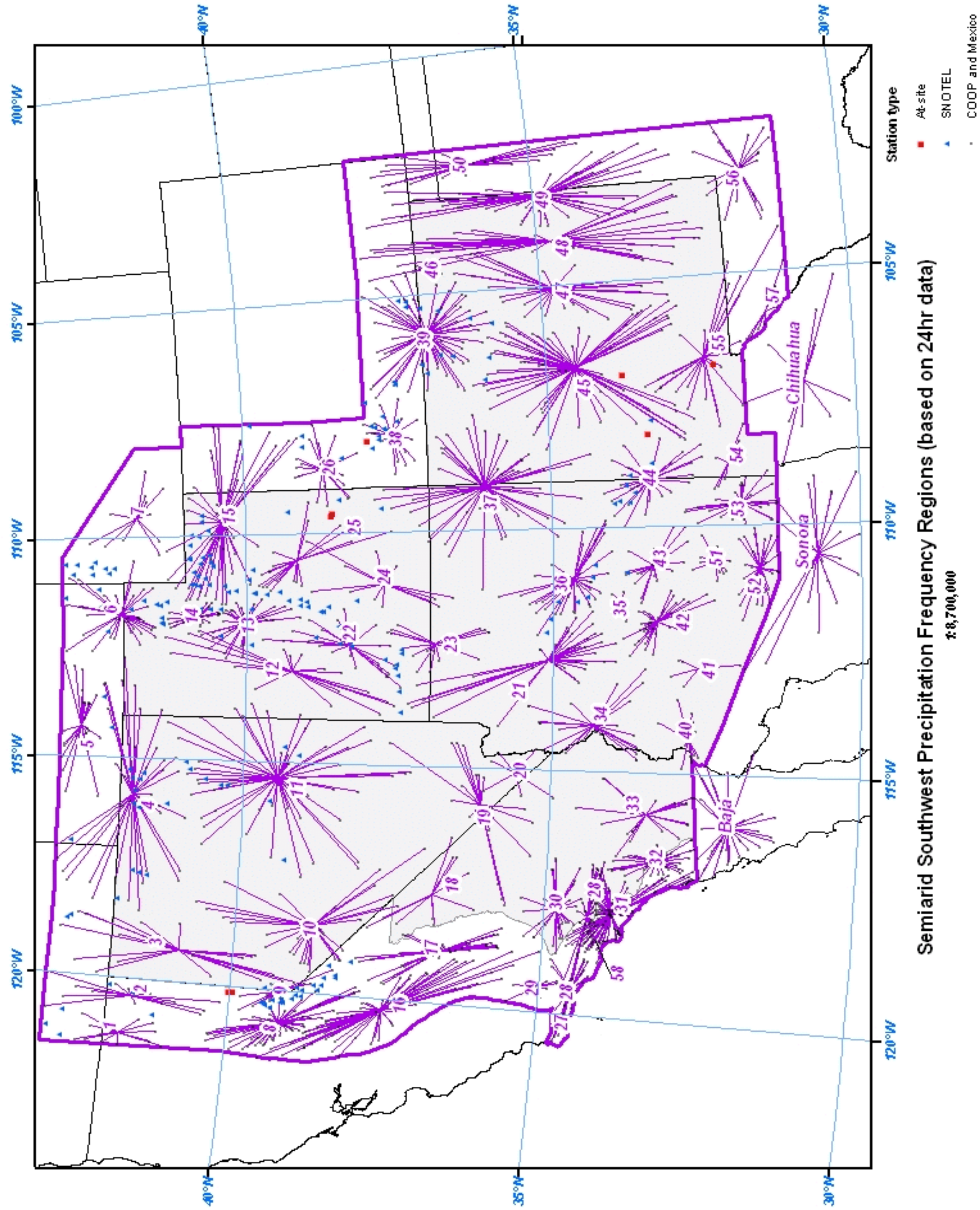

Figure 1. Semiarid Precipitation Frequency project area and new regional groups for 24-hour and longer duration values.

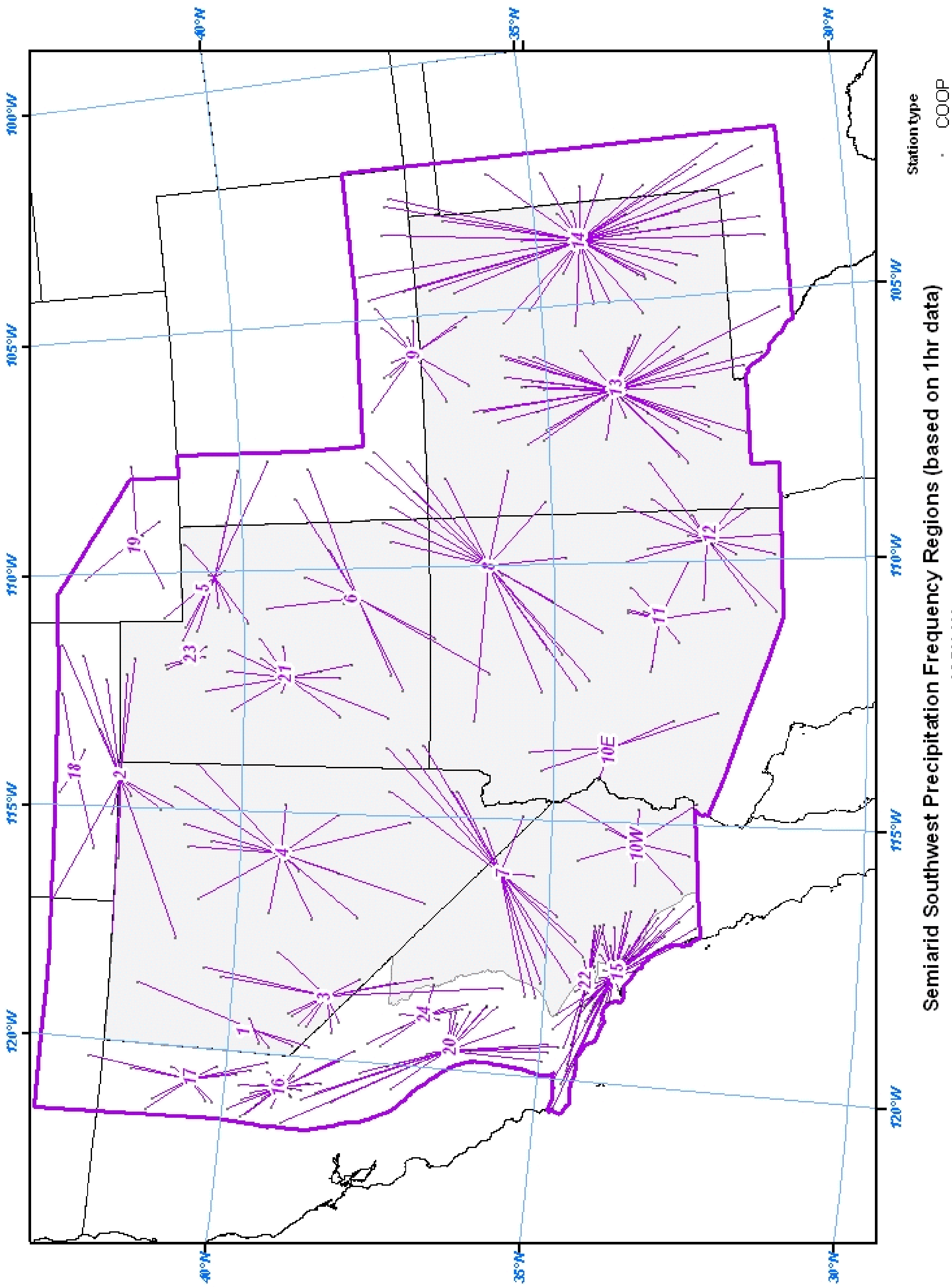

Figure 2. Semiarid Precipitation Frequency regional groups for 12-hour and shorter duration values.

2. Highlights

In the next few weeks, the final precipitation frequency estimates for the Semiarid Southwestern United States will be made available (see Sections 3.1, 3.2 and 5).

Precipitation frequency grids (Table 1) were evaluated in detail for internal consistency. All remaining consistency issues have been objectively identified and resolved. Specifically, discrepancies where there were hourly-only or daily-only observed data that served as anchoring points during the spatial interpolation process for certain durations but not others were addressed. This discrepancy produced unrealistic jumps in the precipitation frequency estimates from 12-hour to 24-hour and 48-hour to 4-day, respectively, at some locations. After verification and/or correction of data accuracy, the use of pseudo data was used to mitigate the unrealistic jumps at 21 daily-only locations. Additional information is provided in Section 3.1, Spatial Interpolation.

A web-page template to provide access to huge volumes of data, including spatial (GIS) data, was developed. The most important milestone this quarter was the population of the PFDS with the final Semiarid Southwest precipitation frequency estimates in anticipation of the public release of the data in the immediate future. Additional information is provided in Section 3.2, Precipitation Frequency Data Server.

Temporal distributions were revised to reflect additional smoothing techniques developed for the Ohio River Basin and Surrounding States Project. We addressed comments from the peer review of the temporal distribution analysis and the trend analysis that were appended at the end of the previous Progress Report. Our responses are appended at the end of this Progress Report. Additional information is provided in Section 3.3, Temporal Distributions and Statistical Trend Analysis.

Progress continues in the development of the geographically-fixed depth-area-reduction (DAR) relationships for area sizes of 10 to 400 square miles in the United States. The name of this project has been officially changed to the DAR project (formerly was depth-area-duration, DAD). Testing and evaluation of pre-processing statistical results are nearly complete. Testing of the semi-objective grouping procedure used in NOAA Technical Report NWS 24 (TR-24) was conducted. Work began on the actual determination of depth area ratios. Additional information is provided in Section 3.4, Depth Area Reduction Project.

3. Progress in this Reporting Period

3.1 Spatial Interpolation

Last quarter the entire matrix of precipitation frequency grids (Table 1) were created using the Cascade, Residual Add-back (CRAB) precipitation frequency grid derivation procedure (see the 22nd Progress Report, Section 4.7).

Table 1. List of all map/grid deliverables.

	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr	1000-yr
5-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
10-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
15-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
30-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
60-min	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
120-min	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
3-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
6-hr	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
12-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
24-hr	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
48-hr	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
4-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
7-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
10-day	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*
20-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
30-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
45-day	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*	G, S, SM*
60-day	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	**G, S, SM**	G, S, SM*	G, S, SM*	G, S, SM*

G = ArcInfo ASCII grid
S = ESRI shapefile of isohyets
SM = State-specific printable cartographic map (PDF format) (emphasized in **bold**)
SM* = State-specific printable cartographic map (PDF format) as time permits

During the evaluation phase of these grids, we discovered a 6 cases where the calculated precipitation frequency (PF) estimates at hourly-only observation locations were not consistent with the spatially interpolated daily precipitation frequency estimates. In these six cases, the spatial trend of the hourly PF estimates suggested much higher daily PF estimates than the CRAB procedure was calculating causing an unrealistic jump in the precipitation frequency estimates from 48-hours to 4-day at that location. This occurred because there were observed data, or anchoring points, at hourly-only stations in the spatial interpolation process for 60-minutes through 48-hours, but not for 4-days through 60-days. Each of the cases was resolved by reviewing the observed data and the behavior of nearby stations. In some cases it was clear that the 48-hour accumulated observed hourly data was less reliable and therefore removed.

Likewise, there were 21 cases involving daily-only stations having inconsistent PF estimates in relation to the spatially interpolated hourly PF estimates. In these 21 cases, the <=12-hour interpolated PF estimates were significantly lower than the calculated >=24-hour PF estimates would suggest causing an unrealistic jump in the precipitation frequency estimates from 12-hours to 24-hours at that location. This occurred because there were observed data, or anchoring points, at daily-only stations in the spatial interpolation process for 24-hours through 60-days, but not for 60-minutes through 12-hours. These cases were objectively identified by using grids that indicated the difference between the 100-year 12-hour and 100-year 24-hour PF estimates.

By using these grids, we were able to differentiate between spatial artifacts and inherently large differences between 12-hour and 24-hour estimates (i.e., geographic areas that could climatologically exhibit such large differences, such as orographic forcing). In general, if the analytical difference between the 100-year 12-hour and 100-year 24-hour gridcell values was >=1.40” in a geographical area, the daily-only stations in that area were scrutinized. After verification of data accuracy, the use of pseudo data was used to mitigate the unrealistic jumps at the 21 locations. These locations were primarily in desert locations, particularly in southwestern Arizona.

The creation of pseudo hourly PF estimates is similar to the approach used previously to alleviate 12h-24h jumps at co-located observing stations. The pseudo PF estimates were generated by applying a spatially-interpolated ratio based on only the co-located stations in the affected region to the daily-only 24-hour PF estimates. The ratio at each co-located station was calculated using the station’s 24-hour PF estimate to its *x*-hour PF estimate. The mitigation provided a smoother, more meteorologically-sound transition from hourly to daily PF estimates. Tests suggested that creating pseudo data for daily-only stations that did not exhibit a large difference from 12-hour to 24-hour resulted in nearly identical PF estimates before and after the inclusion of pseudo data. Therefore, pseudo data was NOT added in areas that did not need it. Locations where a jump between 12-hour and 24-hour estimates could not be expressly proved or disproved were not mitigated. The use of pseudo data was kept at a minimum.

3.2 Precipitation Frequency Data Server (PFDS)

Other than minor bug fixes, the Precipitation Frequency Data Server underwent few changes. Most notably, however, was the development of a GIS/Data download web-page template. The template is designed to provide access to huge volumes of data, including spatial (GIS) data, in a clear and organized manner. The template, which will be used for each individual state, will be first used in the delivery of the final Semiarid Southwestern United States data.

The PFDS was populated with the final Semiarid Southwest precipitation frequency estimates in anticipation of the public release of the data in the immediate future. We have not completed the documentation, however, based on the number of requests, we felt it was appropriate to make the data available as soon as possible as a replacement for NOAA Atlas 2. We expect to complete the documentation in September.

3.3 Temporal Distributions and Statistical Trend Analysis

Temporal Distributions are complete. Temporal distribution graphs were revised to reflect additional smoothing techniques developed for the Ohio River Basin and Surrounding States Project.

HDSC conducted a peer review from April 3, 2003 to May 31, 2003 of the temporal distribution and statistical trend/shift analysis of the annual maximum series in the Semiarid Southwestern United States. The reviewed document is in the appendix of the Twenty-fourth Semiarid Progress Report available at: http://www.nws.noaa.gov/oh/hdsc/current-projects/SemiaridPR24.PDF. We received 15 unique comments. Responses to the peer review are appended to the end of this Progress Report as Appendix A. Suggested improvements from the peer review will be incorporated into the final documentation. There were no comments affecting the results.

3.4 Spatial Relations (Depth-Area-Reduction Project)

Progress continues in the development of the geographically-fixed depth-area-reduction (DAR) relationships for area sizes of 10 to 400 square miles in the United States. Since depth-area-duration (DAD) relates more to probable maximum precipitation applications and storm-centered analyses, the name of this project has been officially changed to the DAR project. Testing and evaluation of pre-processing statistical results using the Chicago, IL and Walnut Gulch, AZ networks are nearly complete. Several tests of a 5-station grouping process were conducted to determine the sensitivity of the semi-objective grouping procedure used in NOAA Technical

Report NWS 24 (TR-24), which is also being used in this study. After careful inspection of the text and graphics in TR-24, we were able to reproduce the pre-processed results using the Chicago, IL data, despite the fact that the TR-24 description of 5-station relative means was somewhat ambiguous. Near the end of this quarter, work began on duplicating the procedures discussed in TR-24 chapter 6, the actual determination of depth area ratios.

A total of 13 different geographic areas throughout the United States have been quality controlled and will be used in the project. The set of curves developed for each area will be tested for differences to determine if a single set of DAR curves is applicable to the entire U.S. Otherwise, separate curves for different regions of the country will be developed.

4. Issues

4.1 USACE Meeting

Geoff Bonnin, representing HDSC, presented a paper at the "World Water and Environmental Resources Congress 2003" sponsored by the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE) in June. The paper, *Recent Updates to NOAA/NWS Rainfall Frequency Atlases,* was well-received and generated significant interest and anticipation of final publication.

5. Projected Schedule and Remaining Tasks

The following list provides a tentative schedule with completion dates. Brief descriptions of tasks being worked on next quarter are also included in this section.

Data Collection and Quality Control [complete]
L-Moment Analysis/Frequency Distribution [complete]
Temporal Distributions of Extreme Rainfall [complete]
Peer review of point estimates [complete]
Trend Analysis [complete]
Spatial Interpolation [complete]
Precipitation Frequency Maps [September 2003]
Final Report [September 2003]
Web Publication [July 2003]
Spatial Relations (Depth Area Reduction Studies) [September 2003]

5.1 Spatial Interpolation

Final grids will be made publicly available. Final cartographic maps (as Adobe PDF files) and GIS shapefile deliverables will be produced during the next quarter.

5.2 Documentation

Final documentation will be written during the next quarter and available on-line through the PFDS web-site.

5.3 Spatial Relations (Depth-Area-Reduction Project)

Software for the DAR computations will be completed in the next quarter and the computations will be performed for 13 areas, and the resulting curves will be tested for differences to determine if a single set of DAR curves is applicable to the entire U.S. or whether curves vary by region.

References

Arkell, R.E., and F. Richards, 1986: Short duration rainfall relations for the western United States, Conference on Climate and Water Management-A Critical Era and Conference on the Human Consequences of 1985's Climate, August 4-7, 1986. Asheville, NC.

Frederic, R.H. and J.F. Miller, 1979: Short Duration Fainfall Frequency Relations for California, Third Conference on Hydrometeorology, August 20-24, 1979. Bogata Columbia.

Frederick, R.H., V.A. Myers and E.P. Auciello, 1977: Five- to 60-minute precipitation frequency for the eastern and central United States, NOAA Technical Memo. NWS HYDRO-35, Silver Spring, MD, 36 pp.

Hershfield, D.M., 1961: Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years, *Weather Bureau Technical Paper No. 40*, U.S. Weather Bureau. Washington, D.C., 115 pp.

Hosking, J.R.M. and J.R. Wallis, 1997: *Regional frequency analysis, an approach based on L-moments*, Cambridge University Press, 224 pp.

Huff, F. A., 1990: Time Distributions of Heavy Rainstorms in Illinois, *Illinois State Water Survey*, Champaign, 173, 17pp.

Lin, B. and L.T. Julian, 2001: Trend and shift statistics on annual maximum precipitation in the Ohio River Basin over the last century. Symposium on Precipitation Extremes: Prediction, Impacts, and Responses, 81st AMS annual meeting. Albuquerque, New Mexico.

Miller, J.F., 1964: Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States, *Technical Paper No. 49*, U.S. Weather Bureau and U.S. Department of Agriculture, 29 pp.

Miller, J.F., R.H. Frederick and R.J. Tracy, 1973: Precipitation-frequency atlas of the western United States, *NOAA Atlas 2*, 11 vols., National Weather Service, Silver Spring, MD.

Myers, V.A. and R.M. Zeher, 1980: A Methodology for Point-to-Area Rainfall Frequency Ratios, NOAA Technical Report NWS 24, Office of Hydrology, National Weather Service, Silver Spring, MD.

Appendix A

HDSC Temporal Distribution and Trend Analysis Review
Comments and Responses
Semiarid Southwest

Tye Parzybok, Debbie Todd, David Riley, Geoff Bonnin

July 21, 2003

Introduction

The Hydrometeorological Design Studies Center (HDSC) conducted a peer review of the temporal distribution and statistical trend/shift analysis of the precipitation frequency estimates in the Semiarid Southwest United States from April 3, 2003 to May 31, 2003. The reviewed document is in the appendix of the Twenty-fourth Semiarid Progress Report available at http://www.nws.noaa.gov/oh/hdsc/current-projects/SemiaridPR24.PDF. This document presents a consolidation of all the review comments with HDSC's response. For the most part, the wording of the comments was unchanged to make sure the meaning was not misconstrued and so individual reviewers can identify their comments. HDSC requested comments from roughly 84 people or agencies; we received comments from only 2. After parsing all of the comments, we found 15 unique comments and they are included in this document.

1 Temporal distribution comments

1.1 Does the 6-hour convective distribution have 7460 cases (Figure 3) or 7757 cases (Figure5)? What about the numbers in Table 1?

Response: The 6-hour convective distribution has 7757 cases. Thank you for noticing the mistake.

1.2 I have been doing some comparison if the Quartile convective cases Figures 5, 7, 9 and 11) with the total convective cases (Figure 3). All these are for the convective cases at 50 Percent total precipitation and all use the plotted value for the 50% line:

a) 6-hour
weighted ave: [(3646*23%)+(1784*39%)+(1474*57%)+(853*68%)]/7757= 38.1%
from figure 3 = 42%

b) 12-hour
weighted ave: [(3976*17%)+(1739*38%)+(1101*57%)+(750*72%)]/7557= 33.1%
from figure 3 = 27%

c) 24-hour
weighted ave: [(4300*14%)+(1341*37%)+(1061*57.5%)+(855*77.5)]/7557= 31.4%
from figure 3 = 28%

d) 96-hour
weighted ave: [(4413*10.5%)+(1213*35%)+(914*57.5%)+(796*79%)]/7336=27.8%
from figure 3 = 20%

I'm not sure that these have any particular meaning but they are interesting. An item that may be as much or more interest is the median value, and a range of values (ie. + or - 10%, 20%, 30%) about the median. Here I am not looking for a single storm to define the median, but a median value at any particular percent of total precipitation.

Response: You have demonstrated the difference between the median and the average of the distributions. We will consider adding additional text to clarify that the curves represent accumulations and that the 50% line represents the median temporal distribution.

1.3 Additional information on the time distribution for shorter duration events would be useful (1, 2 and 3 hour). I realize that this may require shorter duration gaging, but I know you have some. If you can't do this, please recommend an alternative document with reasonable information in it. (Do you remember "task 5", page 10 of the 1990, revised 1992 "Unsolicited Proposal"?).

Response: With limited widespread long period less than 1-hour duration data, we chose not to provide temporal distributions for durations shorter than 6 hours. Many of these events were captured as first quartile events at the 6-hour duration.

1.4 The information in this report will NOT be sufficient to use as a design distribution for use with design hydrologic model for a wide range of small basin semi-arid watershed and urban watershed conditions. I can explain further, but an email is not a good format to do this. There was discussion several years ago during a meeting at the Ariz. DOT in Phoenix, if anyone remembers.

Response: Temporal distributions are presented here for two distinct regions, the Convective and General. The discussion that took place in Arizona was about creating a design distribution that embeds a maximized shorter peak distribution, for instance 1-hour, within a total distribution, for instance 12-hour. It would be very difficult to publish all of the possible combinations of peak hours within each distribution. Instead we provided temporal distributions at different probability levels that would represent these different distribution cases. To create these different design distributions, one could use the information provided in the six-hour distribution in combination with the 12-hour distribution provided.

1.5 I note that the definition for a temporal distribution is based on the use of a one hour peak precip. to define the position within the storm. It appears one hour increments were used for all these computations. When a peak hour occurs at the second hour of a 6-hour duration, is the percent of duration for that point set at 33%? If the peak occurs in the first hour, is the percent of duration for that point set at 16.7% for a 6-hour duration event. I didn't see any discussion on this, and it is particularly important for 6-hour durations, with lesser importance for longer durations. If some adjustment was made, what was the basis for that adjustment? If no adjustment was made, doesn't that skew the data to a larger %-duration by some percentage of the measurement time increment (perhaps 50% of the time increment)? I realize that all the curves have been extended to 0% percent duration and 0% total precipitation. With one hour durations used, I am somewhat surprised that the data plotted to a zero% duration. Did you force the curves to a zero intercept?

Response: One-hour increments were used for all the computations and each accumulation began at zero with the first hour of rain. We did force the curves to both a zero and 100% intercept. We agree that the error associated with using hourly data for six-hour events is greater than with longer duration events. However we consider the amount of sub-hourly data to be insufficient for this purpose. The cases were separated into categories by the quartile in which the most precipitation occurred, not from the 1-hour peak

1.6 Was a similar analysis of temporal distribution of precip. (Huff-type curves) conducted in NOAA Atlas 2 or TP-40, or any earlier publications?

Response: Such an investigation of the temporal distribution of heavy precipitation has not been conducted previously by the NWS.

1.7 How was the Southwest divided into the 2 broad areas of "General Precip." and "Convective Precip."? Why?

Response: The General and Convective Precipitation Areas were established based on seasonality of maximum precipitation and event types. Maximum events in the General Precipitation Area were dominated by cool season precipitation while maximum events in the Convective Precipitation Area occurred in the warm season. We considered various ways of subdividing the region based on the differences in the resulting distributions. We found that the subdivision we used was the most appropriate.

1.8 With regard to methodology, did you select the 3 largest storms for each month each year of record for each station, or only the 3 largest storms for, say, all January's at a particular station?

Response: For every rainfall observing station in the study area that recorded rainfall at least once an hour, the three largest precipitation accumulations were selected for each month of each year for the entire period of record. For example, if a station had data for 30 Januaries than 30*3=90 accumulations were selected from January and so on for each of the twelve months of the year.

1.9 Why only the 3 largest?

Response: It was found that in general choosing the three largest accumulations from each month captured nearly all of the accumulations that were greater than our threshold of 0.5 inches. Many times the second and third largest were not used because the value was less than the minimum threshold set for the particular duration.

1.10 Is it true that for each station you found three 6-hour storms with greater than 0.50" of precip. for each month?

Response: We extracted the highest three 6-hour accumulations for each month but only used the accumulations greater than 0.50" for our calculations. Many months did not have three accumulations greater than 0.50" and some months did not have any. We wanted to capture the heavier events and that is why the thresholds were set.

1.11 Here is just a suggestion for some slight wording additions/changes that may make the bullets on p. 3 just a little more understandable (you decide!):

--first bullet, second sentence: "....(37.5% on the x-axis), all of the storm precipitation (100% on the y-axis) had fallen in these 10% of all first-quartile storms."

--third bullet: "In 90 percent of these events (line labeled 90 on the graph), 50% of the total precipitation fell by the 9th hour (37.5% on the x-axis)."

Under interpreting results, I would rephrase for clarity the second sentence to: "Figures 4 through 11 present the same information but for categories based on the quartile (quarter of the total storm time) when the greatest amount of storm precipitation fell."

Response: Thank you for the wording suggestions. We will incorporate them into the final text.

1.12 On top p. 3 and in a few other places it is said that the Convection area had steeper gradients in the Huff curves. I just don't see this that much, and don't think it is really that significant. What stands out to me is that there is a striking similarity between regions across durations and for various quartiles. Just for instance, for 1st quartile storms, 12 hour duration, the difference between the 10 and 90 lines (80% of all events) at 90% of total storm precip. is about 78% of total duration (90-12) for the Convective Area (Fig. 7A), and is almost identical for the General Precip. Area (93-14=79%). In some of the graphs the lines look tighter for the General precip. area. I don't think these statements should be included as I just don't think they are accurate. If so, you must articulate where this is being observed.

Response: We appreciate your observations regarding similarity of curves between durations and will consider clarification of the text in this area.

1.13 General question: How much variability was noted in these graphs of Huff curves between stations (say in a given region, with elevation differences, etc.)? How much variability in curves was noted between seasons? I think some readers will want to know if you investigated this.

Response: We did not investigate temporal distribution curves at individual stations or seasonality at particular stations because of the amount of data available at each station. We chose to combine data from all stations within the region for a more robust analysis. We did investigate seasonality to discover that stations belonged in one of two regions that were based mainly on which season heavy precipitation fell. These two regions became the General and Convective Areas.

2 Statistical trend/shift analysis comments

2.1 With respect to the randomness test, what does it mean if a station is ruled non-random? (practically, what would cause one station to be ruled random and one not?)

Response: Non-randomness occurs when maxima are not statistically independent within a time series. Causes of non-randomness include small sampling size, the presence of a trend, and/or statistical coincidence. This implies that a non-random station does not necessarily have a trend. However, since different statistical tests may give different results, some stations that are ruled random may test positive for a trend. Annual maximum precipitation data series are widely considered random due to the nature of their formation, i.e., one maximum event per year. In other words, random stations have time-independent annual maximums.

2.2 On Figures 1 and 2 I would note in the caption that only 15% and 13% of all stations shown ANY trend.

Response: Thank you. We will add the percentage of total stations showing a trend or shift to the captions of Figures 1, 2, 3 and 4.

2.3 This is really important stuff! This is at the heart of what is being debated everywhere right now. I strongly encourage the HDSC to put this into a journal paper as soon as possible. No one else has done a thorough trend and shift test of means and variances of hourly precipitation across the nation. Please get this in print!

Response: Similar results were published as Lin, B. and L. T. Julian, 2001: Trend and shift statistics on annual maximum precipitation in the Ohio River Basin over the last century. Symposium on Precipitation Extremes: Precipitation, Impacts, and Responses, 81st AMS Annual Meeting. Albuquerque, New Mexico. Thank you for the suggestion that these results be published as well.